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Exploring the Enigmatic World of the Indian Roller, *Coracias benghalensis*: A Review

Kirti Ojha* and K.P. Singh

Neurobiology Laboratory, Department of Zoology, University of Allahabad, Prayagraj-211002, U.P., India

E-mail/Orcid Id:

KO, kirtiojha14@gmail.com, https://orcid.org/0009-0008-2352-6490;
KPS, kpsald29@gmail.com, https://orcid.org/0000-0002-0958-4351

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Abstract: This review summarized existing knowledge on the neurobiological, behavioural and ecological adaptations of *Coracias benghalensis* (Indian Roller), with particular emphasis on its seasonal breeding patterns and associated neuronal plasticity. The findings reveal that the species exhibits a well-defined reproductive cycle comprising pre-breeding, breeding, regression, and quiescent phases, during which distinct behavioural and physiological changes occur. A key behavioural feature, the ornate aerial rolling display performed by males during the breeding season, is closely linked with courtship, territoriality, and nesting readiness. Neuroanatomical investigations of the hippocampal complex (HCC) have identified three main sub regions—dorsomedial (DMH), dorsolateral (DLH), and ventral (VH) hippocampus—along with four main neuronal types: unipolar, bipolar, pyramidal, and multipolar neurons. Significant seasonal variations in neuromorphometric parameters, including dendritic length, spine density, and soma size, have been documented, particularly during the breeding phase. An increase in dendritic spine density, including mushroom, stubby, and thin spine types, indicates enhanced synaptic plasticity, which is associated with heightened behavioural activity and cognitive demands during reproduction. Ecologically, the Indian Roller demonstrates adaptability across diverse habitats, with higher population densities observed in agricultural landscapes due to abundant prey availability. Its diurnal activity pattern is dominated by scanning behaviour, reflecting its sit-and-wait foraging strategy. The species plays a crucial role as a biological pest controller, consuming a wide range of insect pests and thereby contributing to agroecosystem stability. This review uses a methodical way to compile peer-reviewed studies on *C. benghalensis*. We critically evaluate patterns and gaps in previous research while organizing review across key biological themes. The selection of literature was driven by likely inclusion and exclusion criteria to maintain the accuracy of scientific methodology. Overall, the study highlights a strong correlation between seasonal behavioural displays and underlying neural plasticity, suggesting that hippocampal adaptations facilitate improved learning, memory, and survival strategies during the breeding season. In conclusion, seasonal variations enhance learning, memory and breeding behaviour in *C. benghalensis*, with behavioural and ecological advantages.

Introduction

One of the most spectacular and significant avifauna for ecology, the Indian Roller (*Coracias benghalensis*) is a member of the Coraciidae family and found in various parts of the Indian subcontinent as well as Southeast and West Asia (Ali and Ripley, 1983; Rasmussen and Anderton, 2005). Indian Roller exhibits considerable ecological mobility and adaptability due to its range across a variety of ecological zones, including grasslands, farmland, riverbanks, and sparse-wooded areas. This adaptable behaviour enabled species to survive in both natural and artificially altered habitats, making it a

*Corresponding Author: kirtiojha14@gmail.com

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primary focus of ecological and behavioural studies (Asokan et al., 2010).

However, despite its widespread distribution and frequent appearances, *C. benghalensis* have not received significant attention in integrative biology, particularly when compared to other bird species that have served as classical models in animal behaviour and brain science research. The majority of people are familiar with this bird due to its characteristic sky "rolling" act, which is a challenging behaviour pattern exhibited primarily by male birds during the breeding season (Asokan et al., 2009; Ojha & Singh, 2021a). In this behaviour, the bird rises quickly, descends in an acrobatic manner, and makes wing sounds and calling. This is supposed to be a sign that serves as a means of attracting mates, displaying territory, and exhibiting fitness level (Panicker, 1980; Asokan et al., 2009; Ojha & Singh, 2021a). Although early accounts provided specifics for these actions, it is still unclear how these intricate displays are shaped.

In recent years, there has been an increased attention on understanding the functions of the bird nervous system, including the role of the hippocampal region in regulating space memory, knowledge, and behavioural changes connected to context (Sherry & Hoshooley, 2010; Smulders, 2017). According to Pravosudov and Roth (2013), several bird species have hippocampus that varies greatly with the seasons due to needs including traveling, hiding food, and producing young birds. According to preliminary research on *C. benghalensis* brain biology, there is a pattern in the way its structures and functions change over the year, particularly in terms of neuron morphologies and dendritic structure (Ojha & Singh, 2021a; Ojha et al., 2024). However, these types of studies are rare and restricted, necessitating the creation of a more comprehensive and extensive compilation of current knowledge.

Beyond behaviour and brain meanings, the Indian Roller has a crucial role in nature as an insect-eating predator that greatly aids in controlling pest species in agricultural fields (Mathew et al., 1980; Asokan, 2009). This species is a key component of natural pest control since it feeds on large groups of insects and occasionally small mammals (Parasharya et al., 1994; Vishnu & Ramesh, 2021). According to Ali and Ripley (1983), these ecological efforts not only increase farming benefits but also make it a strong contender as a bioindicator bird, which shows whether a community's health and habitat quality are good.

In the Indian subcontinent's socio-religious landscape, *C. benghalensis* holds a unique cultural position and is often connected to mythology, symbolism, and traditional beliefs (Hatcher, 2020). These cultural connections highlight the importance of understanding this species from a multidisciplinary perspective.

The objective of the current review is to give a comprehensive overview of the literature that is currently available, given the fragmented nature of previous research and the lack of a coherent framework combining behavioural, ecological, and neurobiological factors. The article seeks to lay the underpinning for future research into the adaptation strategies and biological importance of this remarkable avian species by critically analysing earlier studies and finding key gaps.

Methodology

This review synthesizes the literature on *Coracias benghalensis* using a systematic narrative approach. To ensure comprehensive coverage of peer-reviewed research, pertinent papers were obtained from reputable academic databases, such as PubMed, Scopus, Web of Science, and Google Scholar. By combining keywords associated with the species and its biological attributes, such as "avian hippocampus," "neuronal plasticity," "seasonal breeding," "behavioural ecology," and "population dynamics," the search strategy was designed to collect interdisciplinary studies.

In order to maintain scientific rigor, the selection of literature was guided by precise inclusion and exclusion criteria. Anecdotal observations and non-scientific reports were not taken into consideration; only peer-reviewed publications and studies with well-defined methodological frameworks were included. In order to facilitate an organized review of findings, the collected literature was subsequently divided into thematic domains, such as neurobiology, behavioural ecology, population dynamics, and ecological importance.

This review places more emphasis on critical analysis and the integration of findings from many studies than it does on a strictly descriptive approach. To provide an extensive knowledge of the species, patterns, consistencies, and discrepancies in the findings were reviewed. Highlighting methodological flaws in previous studies, such as limited sample sizes, a lack of experimental validation, and inadequate integration of behavioural and physiological data, merited particular emphasis. This method enables for both a critical assessment of the topic as a whole and a summary of current knowledge.

Cytoarchitectural Demarcation of the HCC

The avian HCC is a thin, curved strip of tissue on the dorsomedial surface of the telencephalic hemisphere. For the first time, Ojha and Singh (2021a) transcardially

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perfused the bird, and stained the whole brain with Cresyl-violet stain and then they studied the sections of the highly significant region of the brain, hippocampal complex (HCC) of the Indian Roller in a rostro-caudal direction and three histological distinct sub-fields were recognized dorsal medial (DMH), dorsolateral (DLH), and ventral (VH) hippocampus (Figure 1). DMH region is larger than DLH and VH (Atoji & Wild, 2004). Atoji and Wild (2006) and Striedter (2016) reported, DMH represent a transitional region between the ventral and dorsolateral hippocampus. DMH has a significant role in sexual behaviour (Atoji & Wild, 2006), spatial learning (Lee et al., 1998; Regolin & Rose, 1999), and landmark navigation (Bingman & Mench, 1990). The DMH also processes visual and olfactory information associated with spatial memory (Bingman & Jones, 1994; Atoji & Wild, 2006). Additionally, DMH contributes to sexual imprinting (Sadananda & Bischof, 2004).

Primary afferent and efferent connections with forebrain regions enter and leave the hippocampus with HA (Hyperpallium apicale) at the lateral border (DLH-dorsolateral hippocampus). According to Atoji and Wild (2006), these afferents provide the hippocampus with highly processed visual, auditory, olfactory, somatosensory, and trigeminal inputs.

Breeding biology

C. benghalensis, a tropical seasonal breeder bird, performed distinct rolling behaviour during the breeding season by males to search for a suitable female partner for courtship. This sequence of events characterizes the ornate behaviour: flying high up in the sky, then rolling and falling in a circular motion, with wildly flapping wings and screaming harshly (Ojha & Singh, 2021a; Asokan et al., 2010). The display of fascinating rolling behaviour by *C. benghalensis* is also associated with the nesting behaviour (readiness of nest for mating) and territoriality (Panicker, 1980).

Asokan et al. (2009) divided the reproductive cycle of Indian Roller into four sub-phases; Pre-breeding (February-April), Breeding (May-July), Regression (August-October), Quiescent (November-January). By the aid of the Golgi-Colonnier staining method (Bläsing et al., 2001; Ojha & Singh, 2021a; Ojha et al., 2024) first reported four types of neurons: unipolar, bipolar, pyramidal, and multipolar in the various regions (DMH, DLH) of the one of the most important parts of the brain, namely the hippocampal complex (HCC), which is crucial for learning, memory, and cognitive functions in Indian Roller. Furthermore, during the breeding (pre-breeding and breeding) and non-breeding (quiescent and regression) phases of the male Indian Roller, Ojha and Singh (2021a); Ojha et al. (2024) also report the first-ever connection between seasonal rolling behaviour and neuromorphometric plasticity (soma diameter, dendritic length, dendritic thickness, spine head diameter, and spine neck length) with dendro-spine density in the various neuronal populations in different regions of the HCC. The male Indian Roller active participation in rolling behaviour during the breeding season was also connected with the first reports of different types of spines like mushroom, stubby, and thin, in one of the crucial regions of the brain (Ojha et al., 2024).

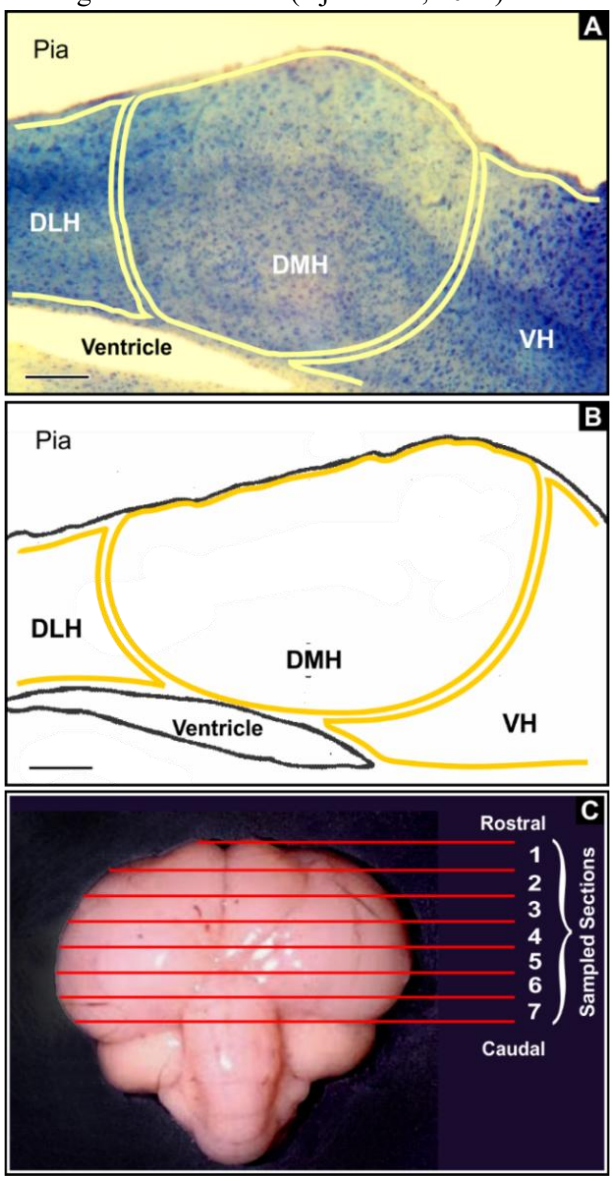

Figure 1. Cresyl-violet stained sections are showing different hippocampus complex (HCC) fields of *C. benghalensis*. DMH, dorsomedial hippocampus; DLH, dorsolateral hippocampus; VH, ventral hippocampus. (B) camera lucida drawing of (A). (C) Representative brain sections sampled from rostral to caudal extent (Ojha & Singh, 2021a).

During the breeding sub-phase of *C. benghalensis*, there was a notable rise in the spine density of various types of neurons that could be attributed to variations in

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the organism's behavioral patterns, which may have represented mental alertness (Ojha and Singh, 2021a; Zito & Murthy, 2002; Ojha & Singh, 2024). In order to entice females, male *C. benghalensis* undergo elaborate sexual display behavior and intensify their activity during the breeding season. Increased spine density and neuronal plasticity are the results of these behavioral changes, which are accompanied by modifications in the bird's endocrinology, physiology, and neuromorphology (Ojha & Singh, 2021a) (Table 1).

Table 1. Behavioural and Neuromorphological findings in *Coracias benghalensis*.

References	Phase/Condition	Aspect	Key Findings
Ojha & Singh (2021a); Asokan et al. (2010)	Breeding season	Rolling Behaviour	Male *Coracias benghalensis* performs aerial rolling display by flying high, rolling, and falling in circular motion with vigorous wing flapping and harsh calls to attract females
Panicker (1980)	Breeding phase	Behavioural Significance	Rolling behaviour associated with courtship, territoriality, and nest readiness for mating
Asokan et al. (2009)	Annual reproductive cycle	Reproductive Cycle	Four reproductive sub-phases identified: Pre-breeding (Feb–Apr), Breeding (May–Jul), Regression (Aug–Oct), Quiescent (Nov–Jan)
Bläsing et al. (2001); Ojha & Singh (2021a); Ojha et al. (2024)	All phases	Brain Region Studied	Hippocampal Complex (HCC), particularly DMH and DLH regions involved in learning, memory, and cognition
Bläsing et al. (2001); Ojha & Singh (2021a); Ojha et al. (2024)	Seasonal study	Neuron Types Identified	Four neuronal types reported: Unipolar, Bipolar, Pyramidal, and Multipolar neurons in HCC region
Ojha & Singh (2021a); Ojha et al. (2024)	Breeding vs. Non-breeding	Neuromorphometric Plasticity	Seasonal changes observed in soma diameter, dendritic length, dendritic thickness, spine head diameter, and spine neck length
Ojha et al. (2024)	Breeding season	Spine Types Identified	Mushroom, stubby, and thin dendritic spines reported in neuronal populations of HCC
Ojha & Singh (2021a); Zito & Murthy (2002); Ojha & Singh (2024)	Pre-breeding and Breeding	Spine Density Changes	Significant increase in dendritic spine density during breeding phases indicating enhanced neural plasticity
Ojha & Singh (2021a); Ojha et al. (2024)	Breeding season	Behavioural–Neural Correlation	Rolling display behaviour correlated with neuromorphometric plasticity and increased neuronal activity
Ojha & Singh (2021a)	Breeding phase	Physiological Association	Behavioural changes during breeding accompanied by endocrinological, physiological, and neuromorphological modifications

Population density

Asokan et al. (2010) employed the line transect method as outlined by Gaston (1975) to examine Indian Roller population density in agricultural lands, river banks, and social forests in Nagapattinam district. In general, the agricultural lands supported relatively higher numbers of birds, followed by the river banks and social forests. Across all studied habitats, population densities were significantly lower during the monsoon. They have been documented seasonal fluctuations in the number of Indian Rollers in habitats such as riverbanks, social forests, and agricultural lands that exhibit high populations in the summer and pre-monsoon season, respectively. In the research habitats, Indian Rollers breed in the summer and have a high population in these habitats due to the availability of good nesting-sites (tree holes/cavities) located on the river banks and social forest. During the pre-monsoon period, Indian Roller

Table 2. Summary of Diurnal Activity Pattern of Indian Roller.

References	Aspect	Description
Asokan et al., 2010	Study Method	Studied diurnal activity using focal animal sampling method
Asokan et al., 2010	Major Activity Categories	Identified five main behavioural activities viz., Scanning, Feeding, Flying, Preening, Resting
Asokan et al., 2010	Dominant Activity	Scanning occupies the highest proportion of time in daily activity.
Asokan et al., 2010	Activity Sequence (High → Low)	Scanning → Feeding → Flying → Preening → Resting
Asokan et al., 2010	Foraging Strategy	The Indian Roller typically uses a sit-and-wait hunting strategy, remaining perched for long periods while carefully scanning its surroundings for prey
Asokan et al., 2010	Perching Behaviour	Birds commonly perch on small trees and electrical wires while searching for prey.
Asokan et al., 2010	Visual Hunting Adaptation	Behaviour indicates highly developed visual hunting ability for detecting insect prey
Asokan et al., 2010	Habitat Dependency	The species depends on open habitats and elevated perching sites, which allow it to easily detect prey and hunt more efficiently
Asokan et al., 2010	Adaptation to Human Landscape	Capability to use artificial structures such as electric lines shows adaptability to human-modified environments
Sivakumaran & Thiyagesan, 2003	Ecological Classification	Identified as a perch-hunting insectivore, spending maximum time in scanning for prey

populations in agricultural regions were relatively high. It may be attributed to the fact that newly recruited young Indian Rollers moved with their parents in search of insect prey, which was typically abundant in these areas (Asokan et al., 2010).

Diurnal activity pattern

The diurnal activity of the Indian Roller is primarily structured around visual prey detection and opportunistic feeding. Asokan et al. (2010) studied the diurnal activity pattern of Indian Roller with the help of focal animal sampling method and divided the time activity into five major categories- scanning, flying, feeding, preening, and resting. Scanning took up the greatest time, followed by feeding, flying, preening, and resting. The sit-and-wait predator nature of the Indian Roller has led to observations of it spending longer periods of time looking for food. When they were looking for food in the study area, they usually perched on small trees and electrical lines (Asokan et al., 2010).

This behaviour reflects several important ecological traits of the bird. It demonstrates a highly developed visual hunting ability, allowing the bird to carefully scan its surroundings for prey. It also shows the species' dependence on open habitats and suitable perching sites, from which it can efficiently observe and capture insects. Additionally, the behaviour indicates a degree of adaptability to human-modified environments, where artificial structures can sometimes serve as perching points.

Earlier observations by Sivakumaran and Thiyagesan (2003) also indicate that scanning for prey accounts for most of the bird's daily activity, reinforcing its classification as a perch-hunting insectivore (Table 2).

Nesting behaviour

Indian Roller displays fascinating rolling behaviour, which is also associated with nesting behaviour (readiness of the nest for mating) and territoriality (Panicker, 1980). They are secondary hole nesters; for breeding purposes, they rely on naturally occurring tree holes or cavities or the abandoned nest of the primary hole builders, such as the Golden-backed Woodpecker (*Dinopium benghalense*) and the Rose-ringed Parakeet (*Psittacula krameri*). It's noteworthy that nest materials were absent from roughly 92% of nests.

According to Lamba (1963) and Panicker (1980), Indian Rollers don't use nest material; instead, their eggs are laid directly on the decomposing wood detritus at the bottom of the hole. This suggests that the bird spends very little time or energy for building a nest, instead making use of natural features already present in its surroundings. In other words, it largely relies on suitable microhabitats available in the environment rather than constructing elaborate nests (Table 3).

Ecological Significance

Indian Roller's ecological significance can be summarized under the following key aspects:

Diet

For the study of the diet of the Indian Roller, around

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the agricultural regions, the regurgitated pellets were opportunistically collected from perch, roost, and nest sites. The gathered pellets were sealed in bags, tagged, and baked at 60°C in a hot-air oven to facilitate identification of any remaining prey (Asokan, 1999; Asokan, 2009).

The major insect groups consumed by the Indian Roller were Coleoptera, Orthoptera, Hemiptera and Hymenoptera (Asokan, 2009). A study conducted in South India by Mathew et al. (1980), from the stomach examination contents of the Indian Roller, revealed that a variety of insect species, primarily belonging to the beetles, grasshoppers, and a few vertebrates like frogs, toads, and *Mabuya* (reptiles), were in their diet.

Besides this, Vishnu and Ramesh (2021) reported that *C. benghalensis* shows a very appalling predation in the Sathyamangalam Tiger Reserve, Tamil Nadu, India, on common wolf snake (*Lycodon aulicus*) and this one is the first report on the feeding of Common Wolf snake by Indian Roller. However, the findings indicated that Indian Rollers are significant insectivorous birds that help control insect populations in their habitat, thereby maintaining ecological balance and reducing the impact of potential crop pests. Accordingly, the presence of Indian Rollers in an area is sometimes considered an indicator of a healthy ecosystem because of their feeding habits. This has led local communities to appreciate and protect them for their ecological role. So, the Indian Rollers can serve as indicators of environmental health and ecosystem resilience. Their presence or absence in an area can provide insights into the overall ecosystem's condition. A thriving population of Indian Rollers

Table 3. Behavioural and Ecological Summary of *Coracias benghalensis*.

References	Aspect	Ecological/Behavioural Significance	Key Observations
Lamba, 1963; Panicker, 1980	Nesting Behaviour	By choosing already existing cavities rather than building a new nest, the bird conserves both time and energy. This behaviour also means that its breeding success often depends on the availability of natural tree hollows in forests or semi-natural habitats.	The Indian Roller is a secondary cavity nester, meaning it does not build its own nest but instead uses natural tree hollows or cavities already created by other birds, such as the woodpecker *Dinopium benghalense* and the parakeet *Psittacula krameri*. The female typically lays her eggs directly on the soft, decomposed wood dust present inside the cavity, without adding any nesting material.
Mathew et al., 1980; Asokan, 1999; Asokan, 2009; Vishnu & Ramesh, 2021	Diet Composition	This behaviour reflects a broad insect-based diet and highlights the bird's important role in controlling insect populations in its habitat.	The diet consists primarily of insects, especially beetles (Coleoptera), grasshoppers and crickets (Orthoptera), true bugs (Hemiptera), and ants and wasps (Hymenoptera). At times, the bird also feeds on small vertebrates such as frogs, toads, reptiles, and even small snakes.
Asokan et al., 2010	Foraging Strategy	Efficient prey detection in open habitats and agricultural landscapes.	The bird typically uses a perch-and-pounce (sit-and-wait) hunting strategy, watching for prey from elevated spots such as small trees, fences, or electric wires before swooping down to capture it.
Parasharya et al., 1994	Agricultural Importance	By feeding on a wide variety of insects, the bird serves as a natural biological pest controller. Its presence helps reduce insect populations that damage crops, thereby potentially lowering the need for chemical pesticides.	It feeds on several harmful crop pests, including white grubs (*Holotrichia*), beetles, and grasshoppers, thereby helping to keep their populations in check.

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Ali & Ripley, 1983	Ecological Role	The presence of healthy populations of this bird often indicates a well-balanced agro-ecosystem with good biodiversity and a healthy availability of natural resources.	Indian Roller relies heavily on abundant insect populations and open habitats; it can also serve as an indicator of ecosystem health. Changes in its presence or numbers may reflect shifts in habitat quality or insect availability.
Asokan et al., 2010	Population Density	Its seasonal activity and behaviour are largely influenced by the availability of prey and suitable nesting sites in the surrounding habitat.	Higher population densities are usually observed in agricultural fields, where food availability is abundant. Moderate numbers are found along riverbanks and in social forestry areas, while the population generally declines during the monsoon season.
Asokan et al., 2010	Seasonal Population Pattern	This pattern likely reflects the breeding season, when adults are often accompanied by newly fledged juveniles as they move around together in search of food.	The population tends to reach its peak during the summer and pre-monsoon months, especially in agricultural landscapes where insect availability is high.

may indicate a balanced and healthy ecosystem (Ali & Ripley, 1983).

Agricultural importance

According to Parasharya et al. (1994), the Indian Roller is a potent bio-control agent against the White Grub (*Holotricha* sp.), a significant subterranean pest that damages the root systems of a variety of crops. By consuming these pests, the Indian Roller contributes to natural pest control, reduces crop damage, and maintains agro-ecosystem balance. Because of this ecological role, the presence of Indian Rollers is often considered an indicator of ecosystem health, reflecting a balanced food web and adequate insect populations (Table-3).

Cultural Significance

C. benghalensis, holds cultural significance in various regions and is known for its striking appearance and distinctive behaviour, which has led to its inclusion in the folklore, art, and symbolism of several cultures in the region. In some Indian myths and folktales, the Indian Roller is associated with good luck and prosperity. Nilakanta (Nīlakaṇṭha) is a revered name of Lord Shiva in Hindu tradition. It is said that he came to be known by this name after he drank the deadly *kalakuta* poison that arose during the churning of the ocean (*Samudra Manthana*), an act that turned his throat blue and earned him the title "the Blue-Throated One" (Hatcher, 2020). Thus, Lord Shiva came to be known as "Neelkanth," which means "blue throat" in Sanskrit and this is the origin of the bird's name.

Discussion

A comprehensive review of the literature on *C. benghalensis* indicates an intricate connection between neural morphology, ecological adaptability, and behavioural manifestation. The apparent connection between seasonal behavioural dynamics and structural plasticity within the hippocampus complex is one of the most striking patterns that emerged from this review. A comprehensive framework is necessary; nevertheless, closer examination of findings across many studies shows both convergence and divergence in interpretations.

Strong evidence for seasonal regulation of neuronal morphology within the hippocampus complex is provided by the neurobiological investigations carried out by Ojha and Singh (2021a) and further explored in subsequent studies (Ojha et al., 2024; Ojha & Singh, 2024). Significant alterations in soma size, spine density, and dendritic architecture are reported in these investigations, especially during the pre-breeding and breeding stages. These results align with well-established theories of neural plasticity, according to which enhanced synaptic connection enhances cognitive abilities including spatial memory and behavioural responsiveness (Zito & Murthy, 2002; Smulders, 2017). The scientists suggest that the increased behavioural demands of the breeding season, such as courtship displays and territorial interactions, are directly linked to these neuroanatomical alterations.

On the other hand, Asokan et al. (2009, 2010)

ecological and behavioural research mainly focuses on observable patterns including diurnal activity, population density, and reproductive cycles. Seasonal peaks in behavioural activity, especially the significance of aerial rolling displays during the breeding season, are abundantly shown by these studies. However Asokan et al. (2009, 2010) don't broaden their investigation to include underlying neurological or physiological factors. When compared with the mechanistic insights provided by neuroscience research, these studies' explanatory reach remains limited, despite offering robust field-based evidence of behavioural diversity.

A complementary but disconnected understanding of the species is revealed when these two bodies of knowledge are compared. Asokan et al. (2010) emphasize external ecological drivers such as habitat structure and prey availability, whereas Ojha and Singh (2021a) emphasize internal neural mechanisms. The absence of studies integrating these perspectives represents a critical gap. For instance, although a relationship between behavioural intensity and neuronal plasticity has been suggested, there is limited direct experimental evidence connecting neural alterations to certain behavioural responses.

Studies of diurnal activity patterns can provide further evidence of the species' cognitive and sensory specialization. Asokan et al. (2010) and Sivakumaran and Thiyagesan (2003), consistently report, the daily activity budget is dominated by scanning behaviour signifying a reliance on visual cues for prey sighting. These behavioural characteristic points sensory processing, which probably require coordinated neuronal activity in several different brain regions, such as the hippocampus and visual centres. Although these studies do not directly investigate neural correlates, their findings align with broader theories of avian cognition and ecological adaptation (Sherry & Hoshooley, 2010).

The ecological adaptations of the species are further demonstrated by studies on nesting behaviour. According to Lamba (1963) and Panicker (1980), *C. benghalensis* is a secondary cavity nester that relies pre-existing tree hollows rather than building nests. Although this method lowers energy costs, it increases dependency on habitat features, especially the presence of suitable nesting locations. It is clear that resource availability and habitat quality have a major impact on population dynamics and reproductive success when considered alongside population studies (Asokan et al., 2010).

The ecological role of the Indian Roller as a biological control agent is consistently supported across multiple studies. Various studies consistently confirm the Indian Roller's ecological importance as a biological control agent. A primarily insectivorous diet has been reported by Mathew et al. (1980) and Asokan (2009), while Parasharya et al. (1994) highlight its usefulness in managing agricultural pests such white grubs. This knowledge is expanded by more recent studies by Vishnu and Ramesh (2021), who reported predation on tiny vertebrates, indicating a broader trophic niche. This progression of findings reflects an evolving understanding of the species' ecological role, moving from a narrow focus on insect predation to a more comprehensive view of its position within the food web.

Despite these contributions, the current literature still has several limitations. Many studies rely on observational methodologies, limiting the ability to establish causal relationships. Furthermore, direct comparisons between studies are hindered by differences in research design, sample methods and analytical frameworks. The understanding of temporal dynamics and adaptive processes is further limited by the dearth of experimental and longitudinal studies.

In light of these limitations, integrative research methods that integrate behavioural ecology with neurobiology, endocrinology, and molecular biology are evidently needed. Advances in these areas hold great potential to uncover the mechanisms behind observed patterns and to place the species in a more comprehensive evolutionary perspective. Future study can offer a more holistic understanding of *C. benghalensis* and its adaptive strategies by bridging the gap between descriptive and mechanistic studies.

Conclusion

In conclusion, four neuronal types in different regions of the HCC are more sensitive to seasonal variation, resulting in a significant increase in neuromorphometric plasticity with dendro-spine density during the breeding season of *C. benghalensis*, which is a characteristic feature of neuronal plasticity. It demonstrates the neurons' efficiency in enhancing *C. benghalensis* neural networking and responsiveness throughout the breeding phase and helps the bird perform overt rolling behaviour as functional (learning and memory) intervention of the HCC, hence enhanced learning and memory capabilities are important for remembering the location of the nest, recognizing potential threats, and efficiently foraging for food to support both themselves and their offspring. Due to their potential role as biological pest control agents, by enhancing such agriculturally beneficial organisms in the field, we can definitely look forward to minimizing the use of chemical pesticides, which have toxic effects on

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the biota. It's important to emphasize that the specific neuronal changes in *C. benghalensis* during the breeding period would require detailed scientific research, including studies involving neuroanatomical, hormone levels, and behavioural observations. These changes can vary among bird species based on their ecological and evolutionary adaptations.

Further research on the neuronal changes in Indian Roller during the breeding period would contribute to our understanding of the reproductive strategies and behaviours of this particular bird species.

Conflict of Interest

No conflict of interest.

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